

PATENT APPLICATION

OVERVOLTAGE PROTECTION CIRCUIT

Inventor(s): Alson Kemp  
1032 Golf Court  
Mountain View, California 94040  
United States citizen

Marshall Chiu  
28 Derby Street  
Daly City, California 94015  
United States citizen

Assignee: Tripath Technology Inc.  
A California corporation

BEYER WEAVER & THOMAS, LLP  
P.O. Box 778  
Berkeley, California 94704-0778  
(510) 843-6200

## OVERVOLTAGE PROTECTION CIRCUIT

5

### RELATED APPLICATION DATA

The present application claims priority from U.S. Provisional Patent Application No. 60/170,963 for OVERVOLTAGE PROTECTION CIRCUIT filed on December 15, 1999, the entirety of which is incorporated herein by reference for all purposes.

10

### BACKGROUND OF THE INVENTION

The present invention relates to overvoltage protection in integrated circuits. More specifically, the present invention provides techniques for protecting integrated circuits from overvoltage conditions of relatively long duration with no significant loss of supply voltage.

15

Every integrated circuit (IC) is fabricated according to a process with a rated absolute maximum voltage. If any of the pins on an IC are subjected to a potential greater than this rated absolute maximum voltage, the device will be destroyed. Thus, the system designer must ensure that the IC is never subjected to a potential greater than the absolute maximum voltage in a given application. However there are situations where the overvoltage problem is unavoidable and some form of protection circuitry is needed in order to protect the IC.

20

One current solution involves the use of a zener diode tied between the IC's power pins and ground. When the system supply voltage ( $V_{IN}$ ) is less than the zener voltage, the zener diode remains off and current flows from  $V_{IN}$  to the IC's supply voltage ( $V_{CC}$ ). The zener diode breaks down and conducts whenever  $V_{IN}$  exceeds the set voltage for the particular zener diode. When the zener diode is conducting, excess current flows from  $V_{IN}$  through the zener diode to ground, thereby holding  $V_{CC}$  at the zener voltage.

25

The main problem with this solution is that the zener diode must pass large amounts of current and dissipate large amounts of heat. As a result, this solution is only acceptable if the over voltage condition is for a short period (e.g., less than 1 or 2 seconds). Otherwise the zener diode overheats, self destructs, and the IC loses its protection.

5 A voltage regulator is another potential solution for the overvoltage problem.

Common voltage regulators such as the LM7812 can be used to limit the supply voltage at the IC. The main problem to this solution is “dropout voltage,” i.e., the minimum difference between the regulator input voltage and the output voltage. The dropout voltage for a device such as the LM7812 is 1.5-2V. In an application such as automotive audio amplifiers, the supply should deliver the maximum available voltage up to, but not above, the rated IC voltage. Any dropout below the rated voltage is undesirable. So if the input is 14V and the rated voltage is 14V, then the regulator should deliver 14V. However, an LM7812, because of its dropout voltage, can only deliver 12.5V under these circumstances.

15 An additional problem with the voltage regulator solution is that the maximum output current may not be high enough to satisfy the system needs. For example, an LM340T-12 can source up to about 2.5A, which only supplies about 30W at 12V. This is an insufficient power level for applications such as an automotive audio amplifier.

20 It is therefore desirable to provide overvoltage protection for integrated circuits using techniques which can handle overvoltage conditions having relatively long durations, and which don’t significantly reduce the maximum output power delivered by the circuits protected.

## SUMMARY OF THE INVENTION

According to the present invention, IC overvoltage protection techniques are provided which are not characterized by the foregoing disadvantages. According to a specific embodiment, an overvoltage protection circuit is provided in series with the input voltage VIN and the IC supply voltage VCC which regulates the current between the two. That is, the circuit functions to reduce the current flow when VCC is too high, and to increase the current flow when VCC is too low. According to a more specific embodiment, the overvoltage protection circuit of the present invention uses a P-channel MOSFET to pass current between VIN and VCC, a voltage divider to sense and scale VCC, an inverting voltage-controlled current source, and a resistor to provide gate drive for the MOSFET. When VCC is low, the MOSFET is driven harder, allowing more current to flow between VIN and VCC. When VCC is high, the MOSFET is provided with less drive, allowing less current to flow between VIN and VCC.

The present invention, which provides protection circuitry to prevent overvoltage breakdown in integrated circuits, should be distinguished from a mere voltage regulator. Voltage regulators typically boost (i.e., increase) or buck (i.e., decrease) an input voltage and output a set constant voltage, and are, themselves, integrated circuits having their own breakdown voltages.

Thus, the present invention provides an overvoltage protection circuit for interposing between an input voltage and a supply voltage. The overvoltage protection circuit includes switch circuitry connected to and passing current between an input voltage node and a supply voltage node, the input voltage node corresponding to the input voltage and the supply voltage node corresponding to the supply voltage. Switch control circuitry senses the supply voltage and regulates current flow through the switch circuitry in response thereto.

A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings.

100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a simplified schematic of an overvoltage protection circuit designed according to a specific embodiment of the present invention; and

Fig. 2 is a more detailed schematic of an overvoltage protection circuit designed according to another specific embodiment of the present invention.

FIG. 1 is a simplified schematic of an overvoltage protection circuit designed according to a specific embodiment of the present invention; and  
FIG. 2 is a more detailed schematic of an overvoltage protection circuit designed according to another specific embodiment of the present invention.

## DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Fig. 1 is a simplified schematic of an overvoltage protection circuit 100 designed according to a specific embodiment of the present invention. As mentioned above, circuit 100 functions to reduce the current flow between VIN and VCC when VCC is too high and increase the current flow between VIN and VCC when VCC is too low. To accomplish this, circuit 100 uses a P-channel MOSFET (Q1) to pass current from VIN to VCC, a voltage divider (comprising resistors R2 and R3) to sense and scale VCC, an inverting voltage-controlled current source (VCCS) (including Q2 and U1) and a resistor (R1) to provide gate drive for Q1.

The VCCS includes R2, R3, Q2, and U1. According to a specific embodiment, U1 is a three terminal bucking DC voltage regulator. For purposes of explanation, we will assume U1 is a +5V regulator. However, it will be understood that the regulation value of U1 may be a wide variety of values without departing from the scope of the present invention. According to this example, Pin3 of U1 is fixed at 5V whenever the voltage at Pin1 is 5V or greater. Whenever VCC increases or decreases, the voltage at the base of Q2 goes up and down proportionally.

When the base of Q2 is one diode drop or more below the emitter, Q2 pulls current from U1, and U1 pulls current across R1 and turns on Q1, thus allowing more current to flow from VIN to VCC. When VCC is “high,” the base of Q2 is also high. This causes Q2 to draw less current from U1, which reduces the current/voltage across R1 and Q1 thereby allows less current to flow from VIN to VCC.

Resistors R2 and R3 form a voltage divider which sets the voltage at which VCC will be clamped. Larger values of R2 result in an increased VCC. Larger values of R3 result in a decreased VCC. This “set” clamping voltage is then compared to the “set” voltage of the

regulator minus one diode drop for Q2. Where, for example, U1 is an LM7805, the regulator “set” voltage is 5V minus 0.6V for Q2 or 4.4V.

According to a specific embodiment, Q1 is a PMOS device in the common source configuration so that the gate is driven below VIN to turn Q1 on. According to other  
 5 embodiments, an NMOS device may be used instead. However, the gate would have to be driven above VIN and this would make the circuit more difficult to implement.

C1 is a filter capacitor that rejects high frequency noise on VCC and helps with loop stability. R4 is not essential to the operation of the voltage clamp but provides a limit on the current that Q2 pulls from U1.

10 Fig. 2 is a more detailed schematic of an overvoltage protection circuit 200 designed according to another specific embodiment of the present invention. Circuit 200 operates substantially the same as described above with reference to circuit 100 of Fig. 1. Circuit 200 may be used, for example, to provide overvoltage protection in an automotive audio power amplifier system. In such an application, the car battery is connected to the 12V\_IN input  
 15 and VCC is connected to the power pins of the amplifier circuit. An LM7805 voltage regulator is used to generate the “set” voltage for the feedback divider. In this embodiment, the ratio of the values of resistors R223 and R225 set VCC to be clamped at 15V. It will be understood, however, that the ratio of these resistors may be varied to set the clamping voltage at any of a range of levels.

20 When the vehicle is running, 12V\_IN is at 14.4V, which is a typical rated voltage for the system. When the car’s engine is started the voltage seen at 12V\_IN can be as high as 70V for a short period of time. Without adequate overvoltage protection, this 70V spike will likely destroy at least part of the amplifier circuit. A zener diode cannot be used in this application because it also would be destroyed. A regulator can be used here as described in



the Background. However, because of the dropout voltage the audio power amplifier would be subject to an undesirable reduction in output power.

According to a specific embodiment and as shown in Fig. 2, two P-type power MOSFETs Q5 and Q6 (IRF9Z34s) are used in parallel to pass the current from 12V\_IN to VCC. Configuring the MOSFETs in parallel reduces the conducting drain-to-source resistance ( $R_{ds(on)}$ ) for the MOSFETs and significantly reduces the dropout voltage (i.e., by a factor of 2) compared to using a single MOSFET. This configuration also allows for shared power dissipation between the two MOSFETs. Thus, if 12V\_IN is held at 70V for a long period of time the circuit would be able continue to protect the amplifier.

Transistors Q7 and Q8 are not part of the over voltage protection circuitry. Rather they serve to disable the overvoltage circuit when the vehicle's remote line is low. With these extra transistors the amplifier will be completely disconnected from the power supply when the remote line is low. The remote line is used to turn the audio power amplifier on and off.

While the invention has been particularly shown and described with reference to specific embodiments thereof, it will be understood by those skilled in the art that changes in the form and details of the disclosed embodiments may be made without departing from the spirit or scope of the invention. For example, an embodiment is described above in which the contemplated application for the present invention is providing overvoltage protection in an automotive audio power amplifier system. It will be understood, however, that the circuits and techniques described herein may be used to provide overvoltage protection in any integrated circuit application. Moreover, the present invention may be implemented using any of a wide variety of integrated circuit fabrication processes. Therefore, the scope of the invention should be determined with reference to the appended claims.